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Analytical review and study on multipath routing protocols*

by

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Abstract: Vehicular Ad Hoc Networks (VANET) constitute a promising technology for Intelligent Transport Systems (ITS). VANET are highly dynamic in their nature because of the movements of vehicles, which are acting as nodes. The routing protocol must be designed for dealing with multiple limiting conditions, like link failures, handoffs, and long congestion periods, which is very challenging. The survey of different routing protocols in VANET provides a significant information for building smart ITS. Accordingly, the present survey is devoted to the existing distinct multipath routing protocols. This review article provides a detailed account on 50 research papers, presenting the different kinds of multipath routing protocols, namely proactive routing protocols, ad-hoc-based routing protocols, Greedy Perimeter Stateless Routing (GPSR), hybrid routing protocols, as well as geographic routing protocols. Besides the classification and cursory description, the present study addresses also several of the important parameters, like evaluation metrics, implementation tool, publication year, datasets utilized, Peak Signal to Noise Ratio (PSNR), and packet end-to-end delay with respect to various techniques considered. Eventually, the research gaps and issues of various multipath routing protocols are presented with the intention of pointing out directions for future research.

Keywords: multipath routing protocols, Peak Signal to Noise Ratio, geographic routing protocols, Vehicular Ad Hoc Networks, proactive routing protocol.

1. Introduction

In the last few decades, the research related to Vehicular Ad Hoc Networks (VANET) and their applications has achieved notable attention, as the

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VANETs are able to connect various access networks for the transfer of user-associated information and the safety-associated information in the mobile environment. VANET technologies are utilized for connecting a high number of vehicles through the wireless medium.

VANETs have, in general, similar operational functionality to that of the Mobile ad hoc network (MANET), and some of the characteristic features rely on MANET (Mukhedkar and Kolekar, 2019). To send a video alert or text message to the vehicles about the steep turn in the path or congestion situation are the most common examples of information transferring via VANETs (Salkuyeh and Abolhassani, 2016). The transmission of video images is one of the challenges faced by the VANET. Streaming of video images permits dissemination of data to passengers as well as drivers, as distinguished from the textual message. Based on cameras switched on the vehicle, a real-time video is fed to the Restricted Stock Units (RSUs), as well as to vehicles, and then to the authorities in order to inform about any incident that occurred on the road (Wang, 2012). Video streaming is also utilized for improving passengers' comfort, such as internet connection, interactive communication, downloading music, etc. Here, an efficient protocol (More and Pawar, 2009) should ensure adequate communication with good reception by the end-user of video streaming based on Quality of Service (QoS), which includes transmission delay, packet delivery ratio, and PSNR (Peak Signal to Noise Ratio), as well as on Quality of Experience (QoE), involving such notions as Mean Opinion Score (MOS), and Structural Similarity Index Measure (SSIM) (Wang, 2012).

VANETs have been paid great attention in research and industrial communities, the latter including electronics, security (Veeraiah and Krishna, 2018), transportation, in particular the automotive networks, and so on (Zaidi, Bitam and Mellouk, 2018). VANET is the collection of nodes for sensing, receiving and sharing the information of dynamic or static character. In principle, the nodes are equivalent to vehicles and they are utilized for communicating with other infrastructure or vehicles to ensure functioning of an intelligent transportation system, in particular - for road safety (More and Naik, 2018a). VANET communicates using two standards, namely the Wireless Access in Vehicular Environment (WAVE), and the Dedicated Short-Range Communication (DSRC) (Marfia and Roccetti, 2010; Xie, Boukerche and Loureiro, 2015; Manimozhi et al., 2018), and has to comprise two types of communication, that is - Vehicle to Infrastructure (V2I) as well as Vehicle to Vehicle (V2V). V2V is the ad-hoc network, in which communication is performed only between vehicles (Biswas, Tatchikou and Dion, 2006; Aliyu et al., 2018b).

VANET routing constitutes a challenging task, because of very pronounced mobility of nodes, dynamically changing topology, and the potentially high number of vehicles. Appropriate response to this challenge should lead to improved situation on the road, including the safety problem, the road congestion, and so on (More and Naik, 2018b; Patel, 2018). In VANET, the routing process is carried out by using definite optimization algorithms, such as, for instance, Ant Colony Optimization (ACO) (George and Rajakumar, 2013). Some routing protocols have been considered in relation to video streaming. It is considered that the most appropriate protocol in VANETs video streaming is the geographic routing protocol, due to the expedient consideration of vehicle location and minimal communication overhead, owing to the use of the neighbor vehicle information only (Xie, Boukerche and Loureiro, 2015; Aliyu et al., 2018b).

The primary intention of this study is to present a possibly extensive survey of the various routing protocols. This survey concentrates on the existing methods, which are used particular research works. The survey takes also into account the utilized datasets, implementation tools, metrics for evaluation, and so on, as these appear in the studies here considered. Moreover, the adopted packet end-to-end delay and Packet Loss Ratio (PLR) are taken for performance evaluation of the suggested multipath routing protocols. The existing techniques have been classified according to distinct classification criteria and for this classification then we try to identify the existing research gaps and problems. Thus, we would like to see this survey to act as an inspiration for the future extensions to the effective routing protocols.

This article is arranged as follows: Section 2 presents the very literature review of the routing protocols. Section 3 reveals the research gaps and the potential future dimensions of multipath routing protocols, and Section 4 elaborates on the results, with a discussion of the survey results. Finally, Section 5 concludes the paper.

2. Literature survey

The distinct research methods adopting various techniques developed for multipath routing protocols in VANET are subject to review in this section. The here applied categorization of multipath routing protocols in VANET is depicted in Fig. 1. Accordingly, the multipath routing protocols are broadly categorized into five groups. These groups are constituted by the proactive routing protocols, ad-hoc routing protocols, GPSR, hybrid routing protocols, and geographic routing protocols. The review of the multipath routing protocols in VANET is meant to provide a possibly clear image of the methods along with their significance, main features, as well as drawbacks.

The distinct research works, in which various multipath routing protocols appear, are successively shortly characterised according to the groups distinguished.

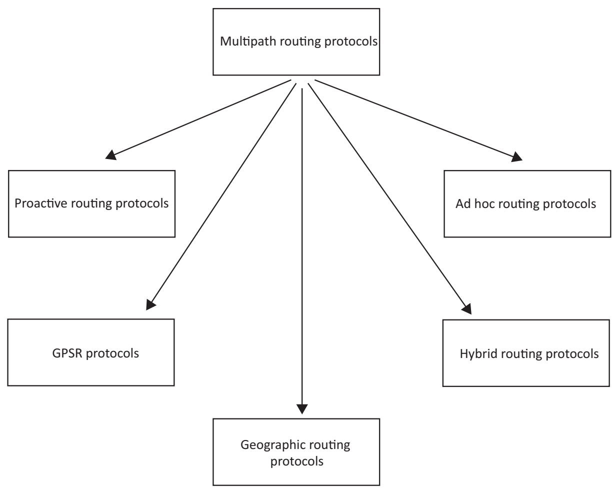


Figure 1. Multipath routing groups of methods considered

a) Proactive routing protocols: The research papers employing proactive routing protocols in VANET, considered in the review, are as characterised below:

Labiod et al. (2018) presented cross-layer mapping for improving the end-to-end delay of video transmission in VANET. This framework made use of the information about the application layer utilising a cross-layer scenario. The data on Medium Access Control (MAC) layer buffered the filling state, temporal prediction video structure and frame type, which allowed the algorithm for delivering the video packets.

Quadros et al. (2014) developed Multi-flow-driven Video Delivery (MVIDE) technique to select the best paths for live video transmission in VANET. MVIDE was combined with Greedy Perimeter Stateless Routing protocol (GPSR) to identify the routes by considering application requirements, vehicle mobility, and characteristics of the multipath structure. The quality of candidates was measured using the known Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) approach for assigning the paths to various sub-streams. Then, the MVIDE was integrated with the Greedy Perimeter Stateless Routing protocol with Movement Awareness (GPSR-MA) protocol, altogether termed GPSR-MA-MVIDE.

Machado et al. (2013) developed a peer-to-peer (P2P) network structure to reduce the bandwidth in VANET. This network structure is designed on the basis of the media distribution graph. During transmission, one peer transmits a video stream to a pair of peers using the P2P framework. The transmitting peer is placed in a road-side unit. Thereby, in the framework of this approach, the vehicles created a P2P network to achieve the maximum number of vehicles within a minimum delay.

Xu et al. (2018) developed the Green Information-centric Multimedia Streaming framework (GrIMS) in the multipath routing protocol in VANET. Here, the cost optimization model was designed based on the reasoning from the queuing theory. There are three heuristic mechanisms that were introduced for achieving energy-saving and high QoE levels in the multi-path selection and in network caching context.

Lai et al. (2016) developed the priority-based multipath routing protocol (PBMP) in VANET for transmitting the video. This framework was utilized for selecting the routes dynamically, based on traffic flows. Traffic information was employed for calculating the transmission probability and subsequently, the next optimal intersection was being selected. After that, multi-paths were constructed based on priority packets for video transmission in order to enhance the delivery rates and recover the broken paths.

Quang, Piamrat and Viho (2014) developed QoE-based routing protocol for video transmission in VANET. The developed QoE-based routing protocol was the combination of QoE and OLSR protocol and in this method mean opinion score (MOS) was used to choose routes. The event-triggered Topology Control (TC) mechanism provided a real-time response to the changes in the network topology.

Mathew (2013) presented a method for transmitting urban video in VANET. This streaming video relies on inter-vehicular communication, which was generated at the road side access point based on mobile nodes. The nodes, which belong to the distribution structure and forward the streaming video, are the relay nodes.

Quadros et al. (2015) developed QoE-aware Receiver-based mechanism (QORE) for improving the videos in VANET. This framework used the Unequal Error Protection scheme (UEP) for reducing the frame loss by distributing the burstiness of losses. Moreover, QORE was combined with Statistical Routing Protocols (SRP) for selecting the relay nodes. Thus, the node decides for itself to retransmit the video so as to improve the capacity of the system.

Yousef et al. (2017) presented the Real Neighborhood and Relative Velocity (RNRV) approach for video transmission in VANET. This approach was utilized for improving the network lifetime and for reducing the routing overhead using Relative Velocity (RV) of neighbors in the transmission range of the vehicle.

Asefi, Mark and Shen (2011) employed a network layer for transmitting the video in VANET. Initially, a quality-driven routing mechanism was introduced for providing video streams through multi-hop communication. The main aim of this approach was to reduce the distortion, start-up delay, and frequency of streaming freezes. After that, the network mobility management techniques were established using Proxy Mobile Internet Protocol version 6 (PMIPv6) for better system performance.

b) Ad-hoc routing protocols: The here considered studies, employing the ad-hoc routing techniques in VANET, are the following ones:

Salkuyeh and Abolhassani (2018) developed a method for mitigating the volume of the Packet Loss Ratio (PLR) in mobile crowdsensing. Here, the PLR was reduced by distributing video packets optimally while meeting the QoS parameter requirements in multipath. Then, the optimal distribution was performed based on the routing parameters: a) connectivity probability of the route, b) route selection for next packet transmission, and c) the routing lifetime.

Xie, Boukerche and Loureiro (2015) presented a node disjoint and link disjoint algorithm for mitigating contention and interference. In this method, I-frames were transmitted based on Transmission Control Protocol (TCP), and the inter-frames were passed based on the User Datagram Protocol (UDP). Then, the TCP Efficiency Routing Metric (TCPETX) was introduced for selecting the better path for TCP transmissions.

Razzaq and Mehaoua (2010) developed an approach based on network coding and path diversity in VANET. This method was utilized for computing the quality of all candidates using Grey Relational Analysis (GRA), and after that, the routes were assigned to various layers. In other words, uppermost priority data was transmitted based on the most stable paths, and the lower priority data were streamed through a limited quality path. Finally, the nearby nodes were selected to record the receiver packets and store them in buffers. These network packets were retransmitted to recover the lost packets.

Al-Ani and Seitz (2016) presented a self-adaptive congestion control mechanism in VANET. ACO was introduced for routing, and Simple Network Management Protocol (SNMP) was employed for computing QoS. Then, the Adaptive Multipath QoS-Aware Routing Protocol (QoRA) was established using ant colony algorithm to determine the multiple paths. After the determination of multiple paths, the congestion control mechanism of QoRA was used to prevent the communication flow when entering into the congested node.

Bisht, Kumar and Mishra (2012) developed Optimized Link State Routing Protocol (OLSR) and an Optimized Ad-hoc on-demand Multipath Distance Vector (AOMDV) for video transmission in VANET. These two protocols were designed based on Advanced Intelligent Driver Model (IDM) to obtain realistic vehicular traces and were tested by altering the Constant Bit Rate (CBR).

Asefi, Cespedes, Shen, and Mark (2011) developed an application-centric routing protocol in VANET for video transmission. The spatial traffic distribution, probability of connectivity model, and queuing-based mobility model were considered for designing this protocol. This routing protocol was developed based on transformation of data between the network, and the application layer for selecting the path.

Wu and Ma (2014) developed a routing protocol for improving end-to-end delivery quality of video transmission in VANET. In this method, each mobile vehicle was considered as a node for communication, with all the nodes having similar transmitting power and the communication range of about 250 meters. Smida, Fantar and Youssef (2018) employed Quality of Delay, and Link lifetime-aware routing protocol to improve the QoS video transmission in VANET. The major goal was to identify the route from the communicating vehicles and to reduce the delay.

Wang et al. (2014) employed Location-Aware multipath video streaming (LIAITHON+) for reducing the communication cost in VANET. This approach considered the highly dynamic topology of VANETs, path length growth, and route coupling effect. This approach has been yet further developed by adding redundancy. Lee et al. (2013) developed a velocity-aware multipath distance vector routing protocol for high mobility (HM-AOMDV), which supports high mobility in VANET. This protocol used the relative velocity and hop counts of both involved vehicles to determine a better path for V2V transmission between the destination and the source nodes. This framework failed to consider other additional devices, like car navigation, Global Positioning System (GPS) board, etc.

c) GPSR protocols: In this subsection we discuss the research works employing the GPSR protocol in VANET. The following ones have been taken into consideration:

Zaimi et al. (2016a) developed enhanced GPSR for improving the video quality in VANET. In this study, the GPSR equation is modified using a greedy process. This framework employed only one hop to pass packets and another hop transmitted other packet for improving the average delay. Zaimi et al. (2016b) presented a new kind of GPSR protocol in VANET. Here, some multipath features with source node were introduced for transmitting the successive packets to more than one path. To solve this issue, the GPRS-2P protocol was established. This protocol was meant to improve the Quality of Service.

d) Hybrid routing protocols: The investigations, in which the hybrid routing protocols in VANET were adopted, are discussed below.

Zaidi, Bitam and Mellouk (2018) developed a Hybrid Error Recovery Protocol (HERP) for transmitting video in VANET. The Sub-Packet Forward Correction (SPFEC) was introduced for recovering burst errors due to route disconnection, and network congestion. HERP dynamically adapted transmission rate, redundancy rate, and re-transmission limit to reduce the transmission delay and network overload. Additionally, HERP employed a reporting technique for controlling the network load and the network condition.

Ayaida et al. (2012) developed a Hybrid Hierarchical Location Service (HHLS) to mitigate overhead. The HHLS resulted from the integration of GPSR and Hierarchical Location Service (HLS). GPSR is responsible for packet routing, while HLS was utilized for getting the destination points when the position of the target node was not known. Thus, the exact target position could be computed.

Husain et al. (2019) presented Intersection-based Link-adaptive Beaconless Forwarding for City scenarios (ILBFC), which was the data forwarding protocol. ILBFC employed information about the location of road intersections, at which a vehicle must tune as a default forwarder. Additionally, the winner relay management technique was introduced to find the speed decay in vehicles. Moreover, ILBFC was simulated in realistic urban traffic conditions.

Xie et al. (2016) developed an error recovery approach, termed Multichannel Error Recovery Video Streaming (MERVS) for video transmission in VANET. MERVS was utilized for transmitting the video through channels displaying varying characteristics, for instance, an un-reliable and a reliable channel. Here, I-frames were passed through a reliable channel, and the inter-frames were transmitted using un-reliable channels. Also, the integration of Scalable Reliable Channel (SRC) quick start and the priority queue were introduced for improving the delay.

e) Geographic routing protocols: The research papers utilizing the geographic routing protocols in VANET, which were considered in the survey, were as follows:

Aliyu et al. (2018b) developed the VANETs Multipath Video Streaming-based Road Features (VMVS-RF) protocol to improve the video quality. This framework was composed of three modules. In the first module, the neighbor information was transmitted. In the second module, the next vehicle node was selected by considering U-turn roads and the junctions. Finally, in the third module, the routing path was estimated using the azimuth angle. In this framework, two paths were considered for video transmission.

Tamilselvi and Kathiresan (2018a) developed the Effective Packet Loss Rate based Multipath Routing Technique (EPLR-MRT) in VANET for video transmission. The transmission was performed through various paths for improving the quality of video streaming using forward error correction. Then, EPLR combined with forward error correction (FEC) was introduced to tackle the issue of minimizing the total number of lost packets.

Salkuyeh and Abolhassani (2016) developed adaptive geographic routing for Video-on-Demand (VOD) transmission in the urban environment. This method identified various independent routes between destination and source vehicles, with the total number of paths being based on the lifetime of the requested video for every route. After that, a closed-form equation was used for computing connectivity probability for the selection of best paths.

Asefi et al. (2012) developed a MAC for the best streaming quality. Then, a multi-objective optimization procedure was applied to the Received Signal Strength (RSS) to reduce start-up delay by tuning the MAC retransmission limit in terms of packet transmission rate and packet error rate (PER) at the vehicle. This framework achieved significantly less playback freezes while introducing slight increase in start-up delay.

Tamilselvi and Kathiresan (2017) developed Bandwidth Aware Multipath Geographic Routing Protocol (BAMGRP) for multipath routing in VANET. In this framework, multiple paths were designed on the basis of ad hoc on-demand multipath distance vector (AOMDV) routing strategy, and then the time-slots were designed for video transmission requests. After that, the minimum predicted available bandwidth was measured, and then the concurrent video transmission requests were arranged based on their bandwidth demand in descending order. Here, the bandwidth was assigned for video transmission.

Razzaq and Mehaoua (2010) developed a model for multipath routing protocol in VANET. This method provided geographic location information for discovering the most suitable pair of routes with minimum coupling effect. For that, the route coupling prevention mechanism was introduced to improve the system performance. Then, Rezende et al. (2015) developed Video Reactive Tracking-based Unicast (VIRTUS) technique. VIRTUS extended the duration of decision nodes for forwarding the packets from single transmission to a particular duration. Moreover, VIRTUS calculated the suitability of a node to relay packets based on a balance between link stability and geographic advancement. Then, the density-aware approach was introduced for selecting relay nodes based on the behaviour of local density.

Hammood et al. (2019) presented Relay Suitability-based Routing Protocol (RESP) using link stability in VANET for video streaming. RESP was utilized for estimating link stability and the geographic advancement of vehicles. In VANET, vehicle density, destination mobility, and vehicle mobility were considered for improving the scalability of protocols. The Expected Transmission Count (ETX) was established for selecting high-quality forwarding nodes for video transmission.

Venkatramana, Srikantaiah and Moodabidri (2017) developed the Software-Defined Networking (SDN) based connectivity-aware geographical routing protocol (SCGRP) for providing ITS. This protocol employed a global view of digital map and network topology to route data packets. SCGRP examined the traffic conditions before selecting the routing path between segments. After that, this method was utilized for predicting the connectivity node as well as link lifetime between the forwarding vehicles to reduce the transmission delay and to increase the PLR.

Huang, Lin and Tseng (2012) developed Geographic Member-Centric Routing (GMR) protocol for VANET. GMR protocol was employed for the reliability of data streaming and aggregating 3G bandwidth in the platoon manner. GMR protocol was utilized for routing multiple sources to single destination to mitigate the packet collision and interference between multiple flows.

f) Other routing protocols: The other routing protocols adopted for VANET, which were accounted for in the review, were the following ones:

Tamilselvi and Kathiresan (2018b) developed the Energy Competent Transmission Mechanism-Based Routing (ECTM-MRA) approach for multipath routing in VANET. ECTM-MRA is composed of two steps. In the primary step, ECTM consists of a vehicle information table and the video review table. In the secondary step, ECTM is combined with a streaming approach that obtains the parameters, like residual energy, transmission speed, and vehicle's degree for low delay, and provides a route for streaming the video.

Wang (2012) developed the Enhanced User Datagram Protocol (EUDP) for video transmission in vehicles. To enhance road safety and to fulfill the requirements of road users, video transmission was introduced for distributing the video data, concerning traffic circumstance, travel information, entertainment, and so on. This protocol used Sub-Packet Forward Error Correction (SPFEC) for enhancing the quality of the video.

Aliyu et al. (2018b) developed the Interference-aware Multipath Video Streaming (I-MVS) for multipath routing protocol in VANET. This method focused on node disjoint optimal paths. Then, the interference-aware video streaming approach was introduced for considering the angular driving statistics of vehicles. Here, the quality of video transmission was obtained using PER. Then, Aliyu et al. (2018c) developed a route coupling minimization mechanism for multi-path video transmission. This method employed a multipath, and packet forwarding parameter to minimize the interference due to the coupling effect. The transmission quality was computed using PER by considering the non-shadowing and shadowing settings.

Eiza et al. (2015) developed Situation-Aware Multi-constrained QoS (SAMQ) approach for multipath routing protocols in VANET. The SAMQ was utilized for computing the optimal paths between communicating vehicles. Then, the single-hop broadcasting technique was established to reduce the routing overhead. Felice et al. (2014) developed the Distributed Beaconless Dissemination (DBD) protocol in VANET for streaming. The DBD employed a backbone-based approach for creating and maintaining high-quality routes regarding vehicles during video transmission. This framework improved the system performance of the MAC layer to tackle the Spurious Forwarding (SF) issues while improving the packet delivery ratio and minimizing the delay.

Mezher and Igartua (2015) developed the Multimedia Multimetric Map-aware Routing protocol (3MRP) for transmitting video in VANET. The main aim was to prevent accidents in the environment of the smart cities. This method used hop-by-hop building-aware forwarding decisions to identify the optimal node. Ikeda, Honda and Barolli (2015) employed a Network-as a Service (NaaS) approach in VANET. NaaS expected that the drivers have access to the Internet-based cellular networks and another fixed AP while driving the vehicle on the road. The capacity of the network is to be utilized by several drivers. The protocol stack 802.11 was considered for transmitting multiple videos over User Diagram Protocol (UDP).

Qadri et al. (2010) presented Multi-Description Coding (MDC) to reduce the PLR in transmission. Then, the spatial partition was done based on macro block ordering. This framework considered driver behaviour modelling, and probabilistic fading models to compute the packet loss ratios. Manimozhi et al. (2018) developed an approach for streaming the video in VANET. In this framework, the nodes were chosen using FEC, and the receiver range was utilized for reducing the packet loss from the raw transmitted video. Moreover, the dynamic nodes were equipped with Onboard Units (OBU), while the static nodes were connected with RSU. Thus, each vehicle would act as a node or a router in the network.

The Preference-aware Fast Interest Forwarding (PaFF) was developed by Wang et al. (2017) for VANET. In PaFF, each and every mobile individual created a Highly Preferred Content Table (HPCT) to manage the status of the node with video playback behaviour and mobility patterns. Then, the forwarder selection approach based on HPCT was introduced for reducing the latencies and improving the reliability.

Chen, Lin and Lee (2010) developed spatiotemporal multicast protocol, which required Spatio-temporal coordination in VANET. The main aim of this work was to compute the zone of forwarding (ZOF) to pass messages in Zone of Relevance (ZOR). Then, mobi-cast protocol was introduced for solving temporal network fragmentation issues.

Fekair, Lakas and Korichi (2016) developed a QoS-based unicast routing protocol (CBQoS) in VANET. This potocol was based on clustering and artificial bee colony algorithm. Here, the clusters were formed around cluster-heads and the cluster-head was selected using QoS criteria. The jitter, link expiration time, end-to-end delay, and available bandwidth were the parameters of QoS considered in this approach.

3. Research gaps identified

The various research gaps as well as challenges, identified in the existing and reviewed literature, are outlined in this section. The issues raised here concern both the apparent shortcomings of the particular techniques considered, and the potential additions to them, which might constitute the subject of future work.

The limitations, associated with the proactive routing protocols are the following ones: the cross-layer mapping approach fails to consider better video packets processing for transmission (Labiod et al., 2018). The structured P2P network fails to reduce backoff time (Machado et al., 2013). GrIMS (Xu et al., 2018) fails to consider the selected nodes to retrieve and cache the contents. The QoE-based routing protocol (Quang, Piamrat and Viho, 2014) never has been examined for different networks and topologies with various scenarios. The method in Mathew (2013) was not applicable in the case of considering the time constraints of live multimedia streaming (LMS) applications meant to reduce the delay. In Quadros et al. (2015), different video features were not considered so that the performance was reduced.

The identified challenges, which are faced by ad-hoc routing protocols were as follows: in Xie, Boukerche and Loureiro (2015), various routing implementations, like GPSR, and Dynamic Source Routing (DSR) were not considered, so that the average time delay was not improved. The major challenges in the GPSR routing protocol that were identified in the survey were as follows: in Zaimi et al. (2016b), only two neighbours were used to test the effectiveness of GPSR-2P. The challenging issues of hybrid routing protocols appear to be: the metaheuristic methods were not considered to compute the retransmission limit and the redundancy rate (Zaidi, Bitam and Mellouk, 2018). Urban scenarios were not considered in simulations meant to analyze the system performance of ILBFC (Husain et al., 2019). In Xie et al. (2016), the algorithms of relay selection and routing were not considered.

The identified challenges, faced by the geographic routing protocols were as follows: the adaptive geographic routing approach (Salkuyeh and Abolhassani, 2016) failed to consider the sub-optimum scheme of packet distribution from connected routes. In Asefi, Mark and Shen (2012), the MAC retransmission limit adaptation scheme failed to adapt with other MAC parameters, like the Contention Window (CW) size. The main drawback of LIAITHON (Wang, 2012) was that the serious route coupling happened between the selected paths. VIRTUS (Rezende et al., 2015) did not consider an error correction mechanism to manage packet loss, and failed to tackle the issues of video transmission of both dissemination and unicast. The method proposed in Venkatramana, Srikantaiah and Moodabidri (2017) failed to consider other routing protocols in order to improve the system performance. The GMR (Huang, Lin and Tseng, 2012) protocol failed to employ other member-centric routing protocols with different categories for better system performance.

The challenging issues faced by other routing protocols were recognised as the following ones: in Xie, Boukerche and Loureiro (2016), the relay selection algorithms and the routing algorithms are not examined for better performance. The method in Wang (2012) failed to consider the EUDP interleaving technique to ignore the errors of video in ad-hoc networks. I-MVS (Aliyu et al., 2018a) did not sufficiently consider the optimization algorithms to maximize the quality of video in VANET. In Felice et al. (2014), the method suggested failed to consider the enhanced adaptive backbone techniques to improve the backbone convergence time. A proper dissemination protocol was not considered for warning other vehicles about any accident on the road in Mezher and Igartua (2015). NaaS from Ikeda, Honda and Barolli (2015) failed to examine roadside AP placement considering road traffic as well as the radio propagation environment. On the other hand, the content centric mobile environment was not considered for sharing the video in Wang et al. (2017). Spatiotemporal multicast (Chen, Lin and Lee, 2010) never has been examined as a multi-mobicast routing protocol to support multiple event vehicles, i.e. the vehicles, for which multiple events (abnormal conditions, failures, etc.) were signalled. CBQoS-Vanet (Fekair, Lakas and Korichi, 2016) failed to choose the right values for the QoS factors for a specific applications, like bulk transfer applications, real-time applications, and multimedia applications.

4. Simple statistical analysis and discussion

The simple statistical analysis of different multipath routing protocol techniques, based on implementation tools, publication year, performance evaluation metrics, utilized datasets, and the results, is presented in this section, along with a cursory discussion.

4.1. Analysis in terms of publication year

This section shows the statistics of the 50 papers, devoted to the subject of this review, and referred to here, according to the publishing year. Table 1, which shows this statistics, clearly conveys the fact of increasing interest in the subject, with the peak in 2018.

Table 1. Analysis in terms of publication year

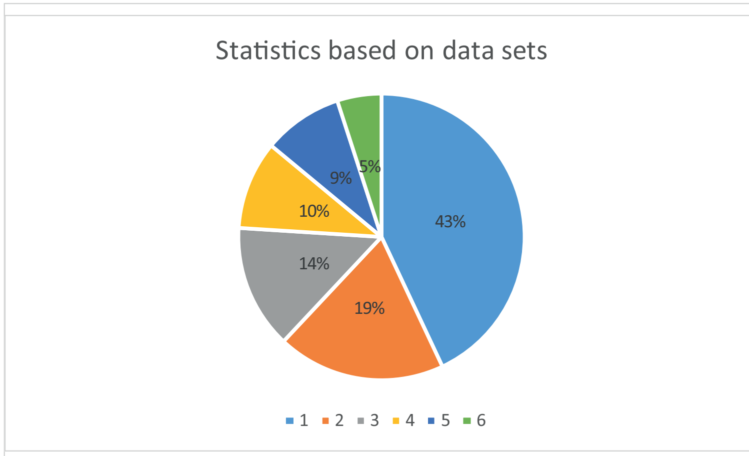
Year of publishing	Number of research papers surveyed
2019	2
2018	10
2017	4
2016	8
2015	7
2014	5
2013	2
2012	5
2011	2
2010	4

4.2. Analysis in terms of the employed datasets

This subsection provides an overview in terms of datasets employed in the distinct research works. Figure 2 depicts the several datasets utilized for studying the multipath routing protocols in VANET. Overall, the relatively commonly used datasets in routing protocols are video quality evaluation tool-set (EvalVid), Traffic and Network Simulation (TraNS), ndnSim, Mobility Model Generator for VANETs (MOVE), VanetMobiSim, Global Mobile System Simulator (GloMoSim), and MININET-Wi-Fi. From Fig. 2, it is clear that the most frequently employed dataset is the EvalVid dataset.

4.3. Analysis in terms of implementation tools

We now turn to the statistics, based on the various implementation tools utilized in the studies here considered. The respective statistics, concerning distinct implementation tools utilized for implementing the effective routing protocols in VANET is depicted in Fig. 3. The commonly utilized implementation tools are MATLAB, OMNeT++, SUMO, Network Simulator NS 2, and so on. It can be easily seen from Fig. 3 that it is SUMO that is the most frequently adopted implementation tool for investigating the routing protocols in VANET.



1: EvalVid; 2. VanetMobiSim tool; 3. Ndn Simulator; 4. MOVE; 5. TraNS Simulator; 6. GloMoSim

Figure 2. Statistics based on data sets employed

4.4. Evaluation metrics applied

The summary account, showing the research papers, dealing with routing protocols in VANET, in terms of the evaluation metrics used, like the number of delivered video packets, route length, Data Receiving Rate (DRR), PLR, freezing delay, Structured Similarity (SSIM), packet delivery ratio, packet end-to-end delay, PSNR, error recovery rate, frame loss, delay, throughput, jitter, control overhead, MOS, and routing overhead, is provided in Table 2. From this ample table, it can be seen, for instance, that among the 50 research papers surveyed, the packet delivery ratio was considered in 11 research papers, while PLR and PSNR were used in 9 papers. Then, 8 of the papers surveyed delay, and average end-to-end delay, and 7 research papers used SSIM, and packet end-to end delay. Further, throughput was referred to in 6 research papers, and freezing delay was used in 5 research papers. Finally, 4 research papers used the number of delivered video packets, jitter, and MOS, while DRR, frame loss, routing overhead, and control overhead were utilized in two of the surveyed research works each.

4.5. Analysis based on packet loss ratio

Table 3 depicts the overview of results from the studies, in which packet loss ratio was considered. From this table it can be clearly seen that the packet-loss ratio within the range of 61%-70% was achieved in three of the studies reviewed, and 71%-80% in one study. Then, the ratio of 81%-90% characterised three studies, while two papers reported the achievement of the PLR of 91%-99.9%.

Table 2. Analysis based on evaluation metrics

Metrics	**Research papers**
Number of delivered video packets	Salkuyeh and Abolhassani (2018); Salkuyeh and Abolhassani (2016); Tamilselvi and Kathiresan (2017, 2018a,b);
DRR	Aliyu et al. (2018a,b)
PLR	Aliyu et al. (2018c); Tamilselvi and Kathiresan (2017, 2018a,b); Salkuyeh and Abolhassani (2016, 2018); Razzaq and Mehaoua (2010); Mezher and Igartua (2015); Qadri et al. (2010); Lee et al. (2013)
SSIM	Aliyu et al. (2018a,b); Xie, Boukerche and Loureiro (2015); Felice et al. (2014); Smida, Fantar and Youssef (2018); Quadros et al. (2015); Zaimi et al. (2016a)
Route Length	Tamilselvi and Kathiresan (2017, 2018a,b)
Packet end to end delay	Tamilselvi and Kathiresan (2017, 2018a,b); Salkuyeh and Abolhassani (2016, 2018); Labiod et al. (2018); Quadros et al. (2014)
Freezing delay	Tamilselvi and Kathiresan (2017, 2018a,b); Salkuyeh and Abolhassani (2016, 2018)
PSNR	Xie, Boukerche and Loureiro (2015, 2016); Wang (2012); Aliyu et al. (2018c); Zaidi, Bitam and Mellouk (2018); Felice et al. (2014); Mezher and Igartua (2015); Wu and Ma (2014); Zaimi et al. (2016a); Smida, Fantar and Youssef (2018)
Error recovery rate	Wang (2012); Salkuyeh and Abolhassani (2016); More and Naik (2018a,b)
Frame loss	Machado et al. (2013); Razzaq and Mehaoua (2010)
Delay	Machado et al. (2013); Razzaq and Mehaoua (2010); Xie, Boukerche and Loureiro (2015); Ikeda, Honda and Barolli (2015); Al-Ani and Seitz (2016); Wu and Ma (2014); Zaimi et al. (2016b); Fekair, Lakas and Korichi (2016)
Throughput	Xu et al. (2018); Bisht, Kumar and Mishra (2012); Ikeda, Honda and Barolli (2015); Chen, Lin and Lee (2010); Manimozhi et al. (2018); Huang, Lin and Tseng (2012)
Jitter	Al-Ani and Seitz (2016); Ikeda, Honda and Barolli (2015); Aliyu et al. (2018c); Asefi, Mark and Shen (2011)
Average end to end delay	Zaidi, Bitam and Mellouk (2018); Bisht, Kumar and Mishra (2012); Asefi, Mark and Shen (2011); Mezher and Igartua (2015); Rezende et al. (2015); Manimozhi et al. (2018); Venkatramana, Srikantaiah and Moodabidri (2017); Husain et al. (2019)
Packet delivery ratio	Lai et al. (2016); Rezende et al. (2015); Ayaida et al. (2012); Hammood et al. (2019); Chen, Lin and Lee (2010); Zaimi et al. (2016b); Fekair, Lakas and Korichi (2016); Huang, Lin and Tseng (2012); Husain et al. (2019); Lee et al. (2013); Zaimi et al. (2016)
Control overhead	Lai et al. (2016); Wang et al. (2014)
MOS	Zaidi, Bitam and Mellouk (2018); Felice et al. (2014); Smida, Fantar and Youssef (2018); Quadros et al. (2014)
Routing overhead	Fekair, lakas and Korichi (2016); Lee et al. (2013)

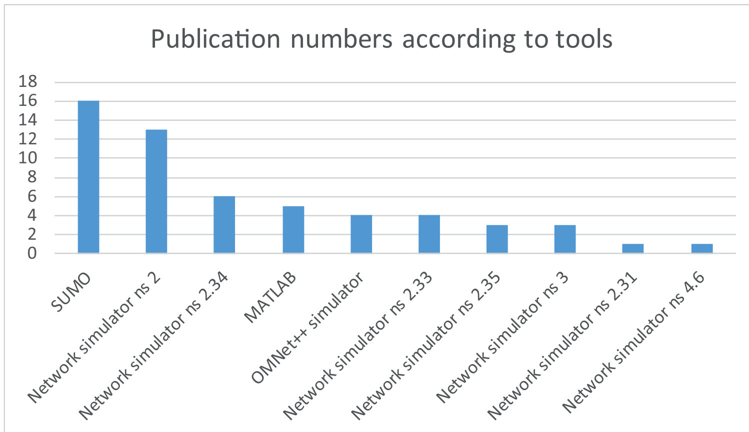


Figure 3. Publication numbers in the survey according to tools employed

4.6. Analysis based on packet end-to-end delay

In this subsection we deal with papers, in which packet end-to-end delay has been considered. Table 4 shows the simple statistics, based on achieved values of packet end-to-end delay. Among all the metrics considered for the evaluation, packet end-to-end delay is one of the most important in terms of demonstrating the effectiveness of the given technique. From this table one can easily see that only two author teams actually used this important metric, but the differences in the achieved values of this metric were quite significant.

5. Conclusion

The study here presented consisted in a survey of the different multipath routing protocols in VANET. The primary goal of this article was to categorize and at least cursorily review the distinct techniques proposed for use in multipath routing protocols, using some 50 research papers acquired from Google Scholar, Elsevier, IEEE, and Science Direct. The existing techniques have been categorized into such groups as GPSR protocol, proactive routing protocols, ad-hoc routing protocols, hybrid routing protocol, as well as geographic routing protocols. A cursory analysis and discussion was also offered concerning the evaluation metrics, utilized datasets, implementation tools, year of publication, and selected evaluation metrics, namely packet end-to-end delay and packet loss ratio. A separate section in this survey suggests the major future directions of development and research, concerning the multipath routing protocols by considering several research gaps and issues. Conform to the results of the analysis and discussion it is the packet delivery ratio that is the most popular evaluation metrics among the research works surveyed, meant for assessing the effectiveness of multipath routing protocols in VANET. The most frequently adopted

Table 3. Analysis using packet-loss ratio

Packet loss ratio	**Research papers**
61%-70%	Aliyu et al. (2018a); Mezher and Igartua (2015); Salkuyeh and Abolhassani (2016)
71%-80%	Tamilselvi and Kathiresan (2017, 2018a)
81%-90%	Salkuyeh and Abolhassani (2018); Razzaq and Mehaoua (2010); Tamilselvi and Kathiresan (2018b)
91%-99.9%	Lee et al. (2013); Qadri et al. (2010)

Table 4. Analysis based on packet end-to-end delay

Packet end to end delay	**Research papers**
-0.0331s	Tamilselvi and Kathiresan (2018a)
-0.0359s	Tamilselvi and Kathiresan (2017)
-0.0484s	Tamilselvi and Kathiresan (2018b)
-0.0542s	Razzaq and Mehaoua (2010)

implementation tool is SUMO, and the most frequently employed dataset is EvalVid. Our future work will be devoted to development of a new multipath routing protocol, based on the knowledge obtained from the present analysis.

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